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LETTER

Microwave absorption studies of the planar equiangular spiral antenna array/epoxy resin composites

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With the development of modern science and technology, electromagnetic (EM) wave absorption materials, as a kind of new functional materials, are not only more and more valued in the application of military fields, but simultaneously also have an extremely widespread application prospect in the civil aspect such as stealth technology of aircrafts, microwave dark room, and electromagnetic interference suppressor [1, 2]. Microwave absorbents are the key in absorbing material research. In recent years, extensive studies have been carried out to develop new absorbents with a high electric and magnetic loss [3–5]. Planar equiangular spiral antenna arrays (PESAAs) might become a novel EM wave absorbent due to their light weight, low lost, remarkable design flexibility, and ease of preparation. However, to the best of our knowledge, there are no reported experimental results on EM wave absorption properties of antenna structures in the open literature.

In this work, PESAAs with different dimension parameters and the magnitude of resistance connecting antenna arms are used as microwave absorbents. The experimental evaluation of composites with PESAAs embedded in epoxy resin is presented, and effects of PESAAs on the reflection properties are investigated.

The epoxy resin (E-44, Resin company in Wuxi, PRC) used in this study was diglycidyl ether of bisphenol-A (DGEBA), which has an epoxy value of 0.41–0.47 mol $(100\ \mathrm{g})^{-1}$ and epoxide equivalent weight near 230 g mol^{-1}.

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The epoxy resin has the permittivity of 3.0–3.4 and the dielectric loss tangent of 0.01–0.03. The polyamide resin (203#, Chemical plant in Tianjin, PRC) was chosen as the curing agent, which has the permittivity of 3.0–4.0 and the electrical resistivity of 10^{11}–10^{12} Ω m. The dielectric properties of both resins are offered by the suppliers. Copper foil with average thickness of 30 μm was used as the material of arms of equiangular spiral antennas. PESAAs were constructed using printed circuit board techniques.

The configuration of PESAAs is shown in Fig. 1, where R_0 and R_1 are the initial radius and outer radius of the spiral antenna, respectively. The edges of the two arms are comprised four equiangular spiral lines, as expressed by

$$r_1 = R_0 e^{0.22\varphi} \qquad r_1{}' = R_0 e^{0.22\left(\varphi-\frac{\pi}{2}\right)}$$
$$r_2 = R_0 e^{0.22(\varphi-\pi)} \qquad r_2{}' = R_0 e^{0.22\left(\varphi-\frac{3\pi}{2}\right)} \tag{1}$$

where r_1 and r_2 are the inward edges of the two arms, $r_1{}'$ and $r_2{}'$ are the outward edges of the two arms. Two arms of the spiral antenna are connected using a resistance, magnitude of which is in the range 150–900 Ω. The space between two antennas (d) is 10 mm.

The epoxy resin was blended uniformly with the polyamide resin in the mass ratio of 2:1. After vacuum defoaming, the mixture was cast into a conventional semi-overflowing die layer by layer until it reaches the desired thickness. PESAAs were embedded in the middle of the resin mixture, and the distance between it and either surface of the sample is 2 mm. Molding was carried out in a hydraulic press at 10 MPa pressure and 80 °C for 2 h, obtaining specimens of 500 mm × 500 mm with thickness of 4 mm for reflectivity measurements. The structure of the sample is shown in Fig. 2.

The absorption characteristics of the samples were evaluated through the arch method based on a HP8757E

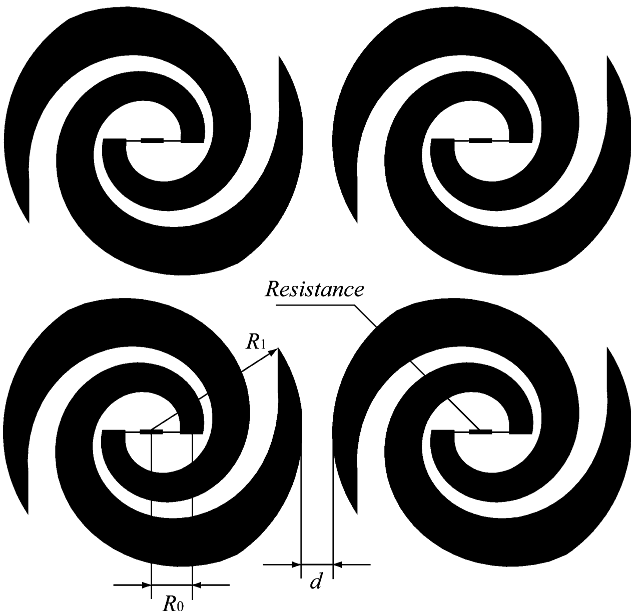

Fig. 1 Geometry of the planar equiangular spiral antenna array

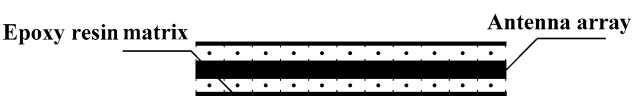

Fig. 2 Cross-section of the sample

network analyzer [6]. By comparing the difference between the reflection from a reference metal plate and that of the absorbers, the reflectivity performance of the absorber in the frequency range of 2–18 GHz was measured. The sample under test was positioned on an aluminum panel (500 mm × 500 mm).

The microwave absorbing properties of the samples containing PESAAs for different R_0 values ($R_0 = 12.5, 6.25, 4.69, 4.17$, and 3.75 mm) are shown in Fig. 3, where other parameters are constants ($R_1 = 40$ mm, the magnitude of resistance = 150 Ω). From the figure, it is found that the initial radius R_0 influences the EM absorption of composites significantly, and the absorption performances of composites first rise and then fall with decreasing R_0. Sample $2^{\#}$ ($R_0 = 4.17$ mm) presents the best absorbing characteristics as compared to the others, which provides the bandwidth below −10 dB (90% absorption) of 6.64 GHz and the minimum R.L. of −19 dB. It can be also seen from Fig. 3 that the frequencies corresponding to the minimum R.L. of composites move toward high frequencies with decrease of R_0.

Figure 4 presents the measured R.L. of samples containing PESAAs, where the outer radius R_1 is taken as a parameter ($R_1 = 37, 40, 43$ mm). The figure shows that the outer radius R_1 influences the absorption of composites greatly. As can be seen, the frequencies corresponding to the minimum R.L. shift to low frequencies for about 2.5 GHz

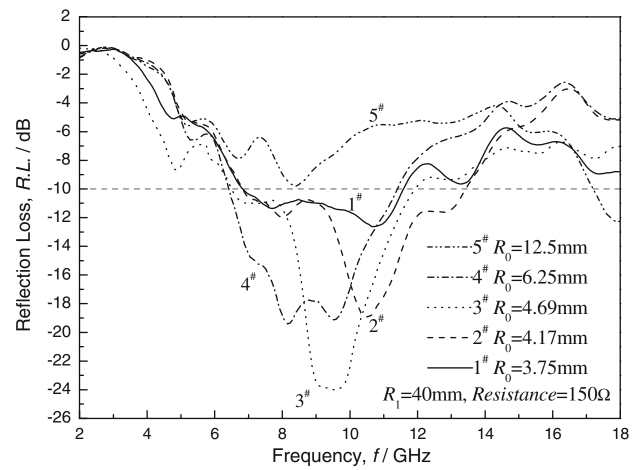

Fig. 3 Effect of the initial radius R_0 on the R.L.

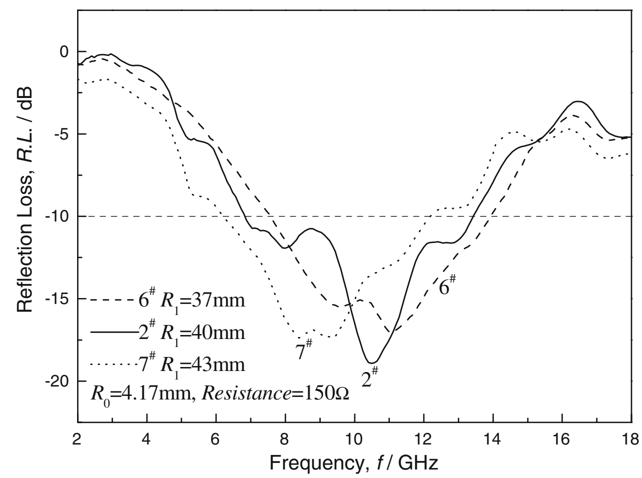

Fig. 4 Effect of the outer radius R_1 on the R.L.

with increasing R_1 from 37 to 43 mm. The microwave absorption performances of composites are reduced in low-frequency band and are enhanced in high-frequency range with decrease of R_1.

Figure 5 shows the frequency dependence of the R.L. of composites containing PESAAs, where the magnitude of resistance is taken as a variable (the magnitude = 150, 400, 650, and 900 Ω) while the others are constants ($R_0 = 4.17$ mm, $R_1 = 40$ mm). As shown in Fig. 5, the minimum R.L. of the samples decreases with the magnitude of resistance increasing from 150 to 400 Ω. When the magnitude is 400 Ω (sample $8^{\#}$), the minimum R.L. is −21 dB at 11.2 GHz. After that, with the magnitude continuing to rise, the minimum R.L. of the composite begins to increase. Obviously, the optimum R.L. is corresponded to a suitable magnitude of resistance, which is 400 Ω in this case. It can be also seen from Fig. 5 that the magnitude of resistance has little effect on the hollows of the curves. For all the samples, the hollows are between 10 and 12 GHz.

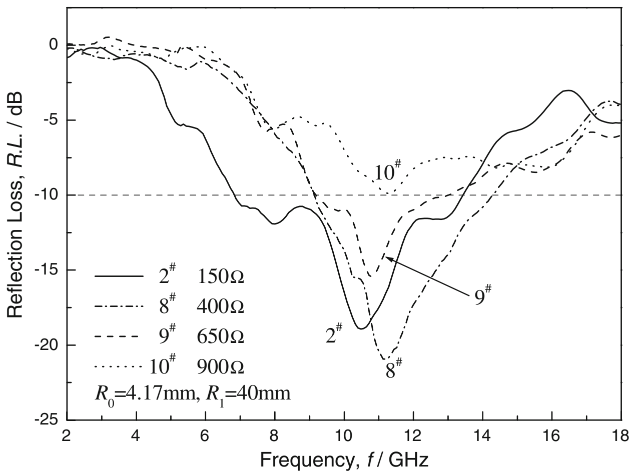

Fig. 5 Effect of the magnitude of resistance on the R.L.

Planar equiangular spiral antenna arrays have the properties of polarization, which means it only captures the specific frequency region of EM waves and converts them into high-frequency voltages and currents in the antenna. Subsequently, EM energy is partly transformed into heat energy by the resistance connecting the two arms of the antenna. This may be the reason that the hollows occur in the absorption curves of all the samples. The properties of impedance and polarization of the antenna arrays vary with changing the initial radius R_0, the outer R_1, and the resistance connecting two arms, which is the reason for different absorbing effect of composites [7, 8].

According to EM field theory [9], the operating band (absorbing band) of equiangular spiral antenna can be approximately expressed as

$$\Delta f \approx f_{\mathrm{H}} - f_{\mathrm{L}} = \left(\frac{A}{R_0} - \frac{B}{R_1}\right) \quad (2)$$

where f_{H} and f_{L} are the highest and lowest operating frequency of the antenna, A and B are constants. Equation 2 indicates that the operating band (the absorbing band) Δf is approximately the function of the initial radius R_0 and the outer radius R_1. The absorbing band expands to low frequencies with increasing R_1 and to high frequencies with decreasing R_0.

When the magnitude of resistance connecting the two arms keeps a low value, the loss resulting from the resistance is so small to consume EM energy effectively, though the input impedance of the antenna array is low and the incident wave can be mostly received. When the magnitude of resistance has a bigger value, the two arms are approximately in a state of open circuit and the currents in the antenna are low. Thus, corresponding to the minimum R.L., the magnitude of resistance has the optimum value [10].

In conclusion, PESAAs would be a kind of promising absorbent for microwave absorption. Composites containing PESAAs exhibit good absorption in the frequency range 6–14 GHz. The absorption is strongly dependent on the dimension parameters and magnitude of resistance connecting antenna arms. With optimum dimension and resistance values, the composite shows R.L. below −10 dB in the frequency region 6.88–13.52 GHz and the minimum value reaches −19 dB.

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